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Spatio-temporal Landuse/Landcover Dynamics in the Coastal Areas of Limbe and Douala IV Municipalities and Implications on Wetland Regulating Ecosystem Services

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Abstract

Globally, wetlands are ecological hot spots and as a result they supply a plethora provisioning, regulating, supporting and cultural services. Despite their functions, wetlands continue to degrade arising from urban developments (population growth and housing developments, road infrastructural developments, urban agricultures and usage of wetlands as dumpsites). These activities operate via land use/land cover changes at different scales in different areas depending on technology and needs of the population. This paper describes the implications of spatio-temporal land use/ land cover (LULC) dynamics in the Limbe I and III Municipality (L1&3Ms) and Douala IV Municipality (D4M) coastal areas from 1986 to 2022 on wetland ecosystem services. This research made use of Geographic Information System (GIS) technique in describing the land use/cover changes in the study areas. Primary data was obtained through field observations, questionnaires and ground truthing aim at confirming the observations on downloaded satellite imageries. Four Satellite images of different years (1986, 1999, 2013 and 2022) were downloaded from the United State Geologic Survey (USGS) Earth Explorer. Images were imported into Erdas Imagine, 2014 where preprocessing was done and Supervised Classification was adopted for the processing of the image to generate a raster format depicting the designed land cover/land uses; especially the wetlands which constituted one of the themes. Maps were generated to show changes in land use/cover which were transposed into tables and figures to show the trends in magnitude of changes, percentage of change and the rate of change. Within 36 years (1986-2022) built-up increased by 0.75km^2 (0.36%) and 1.63km^2 (0.45%) while wetlands retreated by -0.2km^2 (-.96%) and -0.48km^2 (-0.14%) in L1&3M and D4M respectively. Annually, wetlands decreased by - 97.04km^2 and -191.54km^2 while settlements/infrastructures increased by 294.33km^2 and 644.46km^2 over the same 36 year periods in L1&3Ms and D4M respectively. Base on wetland regulating services, changes in LULC has exposes neighbourhoods in L1&3Ms to flood vulnerability comprising the vulnerable, less vulnerable, least vulnerable and most vulnerable areas as opposed to two categories of neighbourhoods in D4M (most vulnerable neighbourhood's and the less vulnerable neighbourhoods). Information on changes in land use-land cover is crucial in delineating impacted areas, understand the type of changes, their spatial patterns and the need for formulating proper urban planning and environmental preservation policies as well as updating these policies with time. GIS analysis of 1986, 1999, 2013, and 2022, indicated that, there have been significant modifications in observed LULC classes (forest cover, farmland and built-up land uses) over L1&3Ms and D4M.

Keywords: Land use/cover, Dynamics, Wetland, Ecosystem services, Geographic Information System, Limbe, Douala IV

1. Background of Study

Land use activities have altered a large proportion of the earth's land surface. Wetlands are specific ecosystems like bogs, bottomlands, fens, flood plains, mangroves, sloughs, swamps, wet meadows, marshes, moors, peat lands, reed swamps and wet prairies (Kometa, 2013). The well-being of humankind is intrinsically tied to the benefits that ecosystems offer (Rivera-Monroy, Kristense Lee, and Twilley, 2017). These benefits are universally known as ecosystem services (ES) and they are classified as regulating, provisioning, supporting, and cultural services (Millennium Ecosystem Assessment (MEA), 2005). A vast majority of wetland benefits accrue to the coastal population which makes it important to conserve these valuable natural resources.

Despite the many values and benefits of wetlands, they are still under threat in many areas where they occur (Goldberg, Lagomasino, Thomas, and Fatoyinbo, 2020), and their deterioration is alarming, particularly in most developing nations where people often rely directly on their ES for livelihoods (Spalding and Leal, 2021). Coastal wetlands in many countries are being affected at an alarming rate and are rapidly transformed and degraded as a result of a combination of natural causes and human activity (Palela, 2000). Lambin and Geist (2007), observed that the major factors influencing land use dynamics include; natural variability, economic factors, technological factors and globalization. Anthropogenic influence on coastal wetland areas have resulted in the transformation of land cover over space and time.

Cameroon is not exempted from the global phenomenon of urban population growth, in fact from 1976-1988, the rate of urbanization in Cameroon grew from 28.5% to 40.4% and between 1988 - 2016 urbanisation rate moved to 55% with a population growth rate of 2.5% per year (National Institute of Statistics (NIS), 2016). Cameroon is highly urbanised with an urban population of 49% and an average urban growth rate of 6.1% by 2018 (Cameroon Assessment Report, 2002; Balgah and Nkemasong, 2018). This rapid urbanization process is highly manifested in the coastal cities of Douala and Limbe due to commercial activities (Fombe & Balgah, 2012).

Coastal areas harbour approximately 38% of the world's population. Over the past three decades, coastal populations have increased globally from 1.6 billion to over 2.5 billion (UNEP 2014b). In 2007, over 1.9 billion (three-quarters) were in developing countries. Due to increasing population over these coastal areas, pressure is exerted on the landscape as societal demands for resources such as food, water, shelter and fuel increases. The major threats to coastal wetlands in Africa include competition for resources, especially water, conversion of wetlands for agricultural and urban purposes and sectoral responsibility for management (Palela, 2000).

The expansion of coastal populations, economic activity and settlement growth in developing countries has resulted in growing pressures on coastal and near-shore ecosystems, such as mangroves/wetlands, marsh, coral reef, and barrier islands (Barbier and Cox 2003; Barbier, Hacker, Kennedy, Koch, Stier and Silliman, 2011; Beck, Brumbaugh, Airoldi, Carranza, Coen, Crawford, Defeo, Edgar, Hancock, Kay, Lenihan, Luckenbach, Toropova, Zhang, and Guo, 2011; Lotze, Lenihan, Bourque, Bradbury, Cooke, Kay, Kidwell, Kirby, Peterson, and Jackson, 2006; Wilkinson and Salvat 2012; Worm, Barbier, Beaumont, Duffy, Folke, Halpern, Jackson, Lotze, Micheli, Palumbi, Sala, Selkoe, Stachowicz and Watson, 2006).

Balgah (2007) observed that very few landscapes on the Earth's surface have not been altered or are not gradually being altered by human for one reason or the other. Mangrove forest vegetation constitutes the dominant wetland ecosystem of the humid tropical coast of Cameroon that is currently subjected to considerable human-induced changes (Asangwe, 2009). As these ecosystems disappear or are degraded, there will be less protection against short-lived natural disasters with immediate and often extreme impacts, such as flooding and storm surge, (Barbier 2014; Barbier *et al*. 2011; IPCC Working Group II 2014; Spalding, Ruffo, Lacambra, Meliane, Hale, Shepard and Beck 2014; Temmerman, Meire, Bouma, Herman, Ysebaert, and De Vriend 2013). The repercussions are being felt by the coastal dwellers in these areas in different dimensions.

Also, global climate change manifested via sea level rise (SLR) and increased temperature/ rainfall are considered as prime drivers for mangrove deterioration and change in coastal ecosystems, resulting to increasing risk such as coastal flooding (MEA, 2005; Friess, Rogers, Lovelock, Krauss, Hamilton, Lee, Lucas, Primavera, Rajkaran and Shi 2019; Goldberg *et al*., 2020, IPCC Working Group II 2014; Spalding *et al.* 2014).

Several studies have confirmed the adverse effect of LULC change on ecosystem services. For instance, a decrease in vegetation cover (forests, woodland/shrub/bushland) has led to the decline of many ecosystem services in Ethiopia (Woldeyohannes, Cotter, Biru, Kelboro 2020; Kindu, Schneider, Teketay, Knoke 2016; Tolessa, Senbeta, Kidane 2017; Gashaw and Gebre-Egziabher 2018;). Likewise, urban and agricultural pressures on other land resources have brought the reductions of several ecosystem services in China (Jiang, Sun, Liu, Shan, Zhang 2019; Liang, Zhong, Zeng, Chen, Hua, Yuan, Wu and Gao 2017; Zhao, Yang, Zhao, Zhao 2004;) and Nigeria (Arowolo, Deng , Olatunji and Obayelu 2018). Due to the significance of such changes on the coastal areas, monitoring changes in land use-land cover is a high priority area for research.

2. The Problem

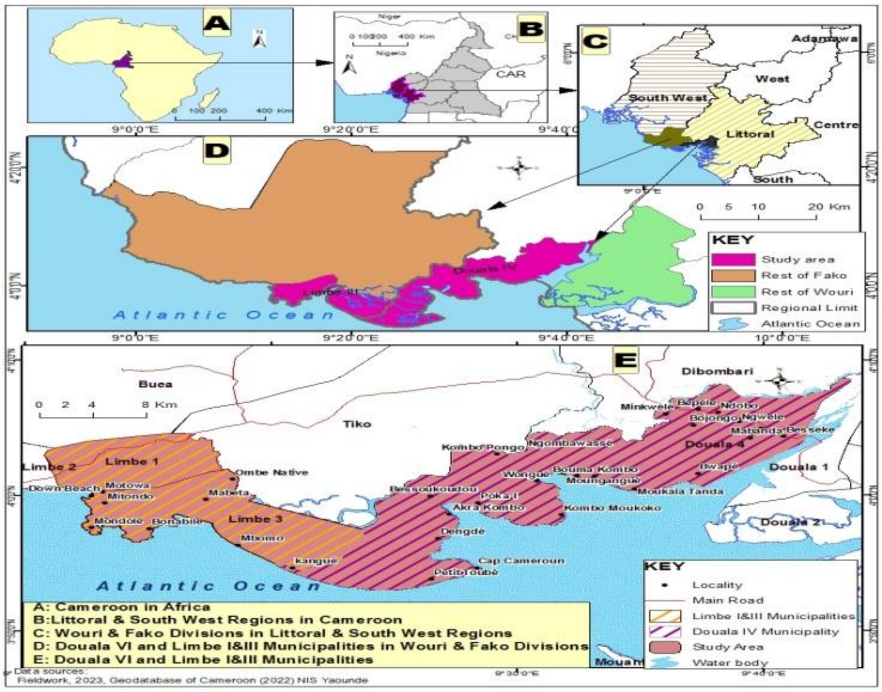
Although land use practices across coastal environments vary greatly, their ultimate outcome is the way they alter the functioning of wetland ecosystems. Coastal communities within the study areas have used wetland resources to meet their material, social, cultural and spiritual needs and in this process modify the functioning of ecosystem services provided by these wetlands especially the regulating services (curbing coastal storms and flooding). These changes are attributed to increasing urban developments manifested via increasing housing developments to cater for the growing population, infrastructural developments and urban agriculture. 'The rapid increase in population (from 101839/250626 inhabitants in 2005 to about 119499/ 392015 in 2020 for L1&3Ms and D4M (National Institute of Statistics (NIS) 2010 and Limbe City Council (LCC) and Douala City Council (CUD), 2022), stand as the main driving force behind land use/ cover dynamics. Both population growth and urban development variables have created pressure on land hence encroachment on wetlands and this has led to changes in both size and productivity of the wetlands thereby exposing the areas to flooding and other risks. Consequently, the focus of this paper is to study the spatio-temporal land use and land cover dynamics on wetland provisioning services in the Douala IV and Limbe coastal areas.

3. Study Areas and Methods

3.1 Study Areas

Geographically, Douala IV Municipality (D4M) is located at latitude “4^o 40 and 4^o 80" North and longitude 9^o 32 and 9^o44" East of the Greenwich Meridian. Bonaberi Municipality is located in the Douala IV Sub-Division in the Wouri Division, North of the Littoral Region. This Municipality covers a surface area of about 890Km^2 of the total area of Douala city (Administrative Units of Cameroon, 2018). This Municipality is made up of 11 major urban neighborhoods which are; Ngombawassa, Kombo, Moukanda, Bwape, Mabanda, Bonassama, Sodiko, Bodjongo, Ndobo, Njebale and Bonamatoumbe.

On the other hand Limbe I and III Municipality (L1&3Ms) constitute two of the three Sub-divisions of Limbe. They are located between “3^o 95 and 4^o 00" North and longitude “9^o 12 and 9^o 25" East of the Greenwich Meridian covering 212km^2. They are bordered in the South by the Atlantic Ocean, in the North and North-East by Buea and Tiko Sub-divisions respectively and in the West by Idenau Sub-division. It is made up of some neighbourhoods such as; Mbonjo, Mabeta, Unity Quarter, New-Town, Motowoh, Mabeta New Layout, Cassava Farms, Coconut Island, Down Beach, GRA Extension, Lower Mawoh, Lumpsum and Bonadikombo. D4M and L1&3Ms make up part of the low-lying basin which runs from the foot of Mount Cameroon (4095m^2) to the southern part of Kribi (Gaston, 2009). These coastal areas enjoys equatorial climate with two seasons (hot and wet). The annual rainfall of D4M is more than 4000 mm with average daily temperatures of 25˚C while L1&3Ms have average annual rainfall between 3100mm - 5000mm with average daily temperature of 24˚C (NASA, 2022). Map 1 shows the geographical location of the study areas.



Map 1. Location of Study Areas

Source: Field Work 2023, Geo database of Cameroon, 2022, NIS

3.2 Study Methods

Exiting shapefiles on the administrative limits of Cameroon were gotten from the National Institute of Cartography (NIC) and the National Institute of Statistics (NIS) Yaoundé which constitute part of the Geo database of Cameroon for 2021. The shapefiles were displayed in ArcGIS 10.3, for further analaysis. The administrative limits shapefiles were corrected based on field realities. The Global Positioning System (GPS) Receiver; Mark Garmin 62 was used to generate coordinates, recorded in XYZ giving the location of a feature in longitude, Latitude and Altitude. The coordinates were offloaded directly into QGIS 3.6 for processing. Coordinates for some of the wetlands were gotten from field with the GPS. The coordinates were imported into ArcGIS 10.3 in which the attributed tables were created for subsequent analysis.

Four Satellite images the years 1986, 1999, 2013 and 2022 were downloaded from the United State Geologic Survey (USGS) Earth Explorer and processed with the objective to portray the spatio-temporal dynamics of urban expansion and implication on wetlands/ecosystem services in the study areas. Table 1 presents the characteristics of each of the images used. The Images was imported into Erdas Imagine, 2014 where preprocessing was done. The raster format was imported into ArcGIS 10.3 where it was converted from raster to vector format before the extraction and symbolization of the different landuse to produce the landuse map and the spatial distribution of the wetlands per municipality.

The use of 1986 as the base year was because it was the year where Limbe sub-Division was created (1986) and one year before the first censors (population and housing) was taken (1987) in Cameroon and equally it was 10 years after the Bonaberi-Industrial zone was created (1977) which are considered as significant drivers of LULC dynamics. The study used 13 years, 14 years and 9 years intervals due to the availability of cloud-free images that portrayed visibly the phenomenon under study. These images were downloaded for the months of May and June representing the spring and summer periods (dry season) as they were less cloudy considering that images for coastal areas are very cloudy especially those of the winter periods (rainy season). The usage of an irregular interval also aimed at comparing LULC changes within different periods which are important considerations in looking at planning prospects over time.

Table 1. Characteristics of Each of the Images Used

S/N	Image date	Satellite Censor	Downloaded Date	Spatial Resolution	Number of Bands	Path/Roll	Cloud Cover
1	12/04/1986	LT5	12/10/2022	30m	7	187/057	6%
2	08/04/1999	Lat 7 ETM+	13/10/2022	30m	8	187/057	15%
3	04/12/2013	Lat 08 OLI_TIRS	17/11/2022	15m & 30m	11	187/057	10.21
4	10/06/2022	Sentinel 2B	21/12/2022	10 - 60	13		1.3

Another satellite image that was used for the work was Google Earth image; last update dates 18th December 2021. This image was downloaded using the software Universal Map downloader 9.30 and imported into ArcGIS 10.3 in which digitization of the wetlands was effectuated. The images also permitted the digitization of the hydrographical network, road network and other themes that were important for the study. It was also used to carry out the inventory of all the wetlands across Douala IV and Limbe Land III of which could not have been easy without a clear image like that of Google. This is because the Landsat Image with 30m resolution could not be that accurate. Still from the USGS the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Image captured in 2017 was downloaded for the production of the relief map of the study area. This was done in ArcGIS 10.3. The processed satellite images and field data enabled the production of 6 major LULC classes (Table 2).

Table 2. Description of Major LULC Classes

LULC Type	Description
Wetlands	Permanent and seasonal grasslands along lake, river, and streams, marshy land and swamps.
Built-up area	This class describes the land covered with buildings. It includes commercial, residential, industrial and transportation infrastructures.
Agricultural /farmland	All cultivated and uncultivated agricultural lands areas, such as farmlands, crop fields including fallow lands/plots, and horticultural lands.
Dense Forest	Slightly modified vegetation cover within the study areas
Light forest	Modified vegetation cover within the study areas
Mangroves	Marshy land and swamps
Water body	These includes; rivers, springs, streams within the study areas

Source: Fieldwork, 2022

To determine the rate of land use/cover changes the magnitude of change, percentage of change and the annual rate of change were calculated.

Magnitude of change= LU situation of the New Year –LU situation of the previous year

Percentage of change (trend) = $\frac{\text{Magnitude of change}}{\text{Base year}}$ x 100

Periodic rate of change = % change x Difference in the study year

Over All Accuracy: $\frac{\text{Total Number of Correctly classified pixel}}{\text{Total Number of Reference Pixels}}$ X 100/1

4. Findings and Discussion

4.1 Main Findings

The physical environment of D4M and L1&3Ms have undergone diverse mutation from 1986 to 2022. The spatio-temporal extents of LULC over the study areas are shown on Maps 2, 3, 4 and 5, while the corresponding total area (km^2) and percentages covered by each of the land cover types in 1986, 1999, 2013 and 2022 are presented on Figures 1, 2, 3 and 4.

4.1.1 Spatial Evolution of L1&3Ms and D4M in 1986

The total area and percentage covered by each of the LULC types in 1986 are presented in Figure 1 while Map 2 provides their corresponding spatial extents.

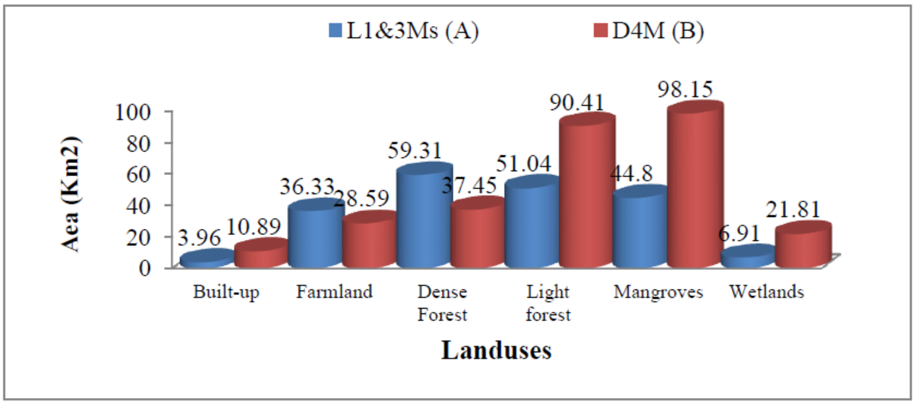
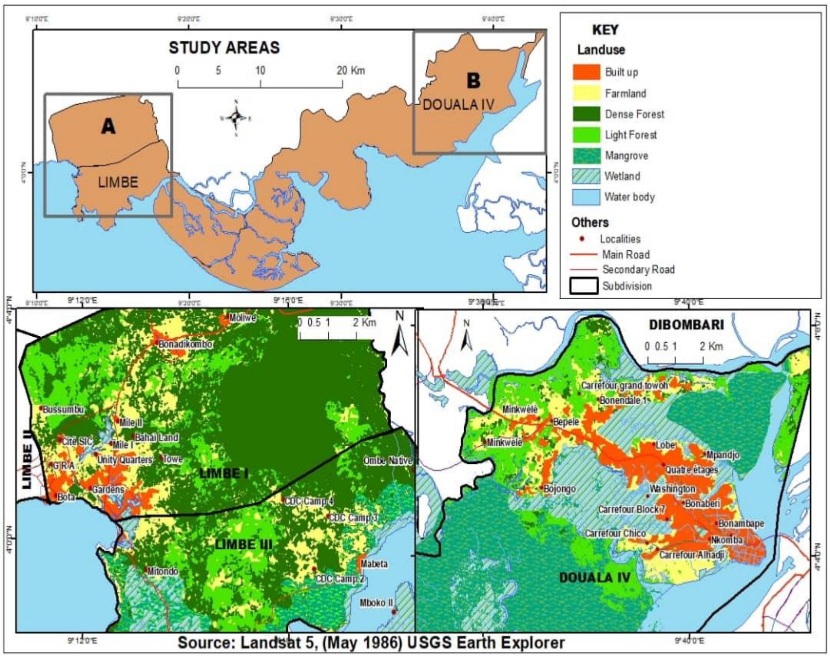


Figure 1. LULC Situations in 1986 in L1&3Ms and D4M

Source: Derived from Landsat 5, 1986 LULC Data for D4M and L1&3Ms

From the clustered cylinder (Figure 1), the most dominant LULC class for 1986 was light forest and mangroves and it occupied 90.41km^2 (25.67%) and 98.15km^2 (27.87%) in D4M and Light Forest occupied 51.04 km^2 (24.56%) for L1&3Ms. This implies that the remaining 118.95km^2 (57.25%) and 157.64km^2 (44.76%) of land in both study areas were occupied by dense forest 59.31km^2 (28.54%) and 37.45km^2 (10.68%) farm land 36.33km^2 (17.48%) and 28.59 km^2 (8.13%), 3.96 km^2 (1.91%) and built up 10.89 km^2 (3.09%). Wetland 6.91km^2 (3.33%) and 21.81km^2 (6.19%) and water bodies occupied 12.44 km^2 (5.99 km^2) and 58.90 km^2 (16.72%) in L1&3Ms and D4M. By implication, built-up and farmlands constituted the major drivers of wetland areal change in 1986, occupying 40.29km^2 (19.39%) and 39.48km^2 (11.22%) for both Municipalities (L1&3Ms and D4M respectively).



Map 2. LULC Situations in 1986 in L1&3Ms (A) and D4M (B)

Source: Landsat 5, 1986 and Fieldwork, 2023

4.1.2 Spatial Evolution of L1&3Ms and D4M in 1999

The total area and percentage of LULC classes in the year 1999 are presented in Figure 2 while Map 3 provides spatial extent in the study localities.

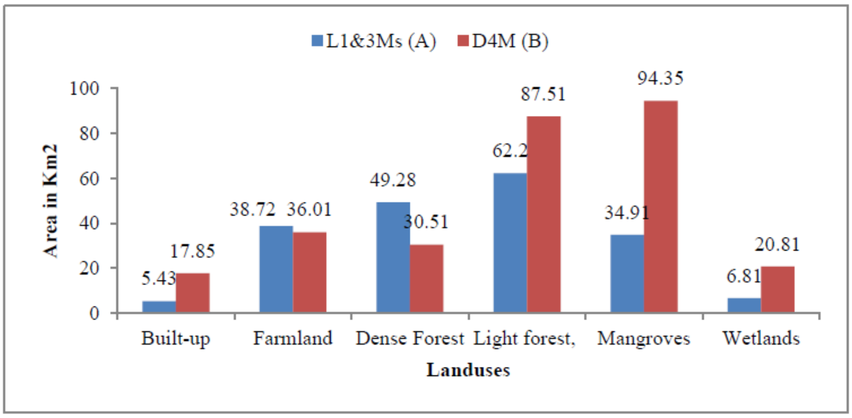


Figure 2. LULC Situations in 1999 in L1&3Ms and D4M

Source: Derived from Landsat 7 ETM+1999 LULC Data for D4M and L1&3Ms

From the clustered columns (Figure 2), in 1999, built up area occupied 5.43km^2 (2.61%) and 17.85km^2 (5.07%) of the total 207.79km^2 and 352.20km^2 of land cover in L1&3Ms and D4M while wetland vegetation occupied 6.81km^2 (3.28%) and 20.81km^2 (5.91%) of the total land cover of both study areas respectively. From Figures 1 and 2, built up has increased by 1.47km^2 (0.7%) and 6.96km^2 (1.98%) between 1986 and 1999 in L1&3Ms and D4M respectively. In the same light, wetland areas reduced by .01km^2 (-0.05%) and -1km^2 (0.82%) respectively. Thus, an increase in farmland from 36.33km^2 -38.72km^2 (17.48% - 18.63%) and 28.59km^2 - 36.01km^2 (8.13% -10.22%) respectively, have contributed greatly to reducing the wetland areas of 1999 in L1&3Ms and D4M.

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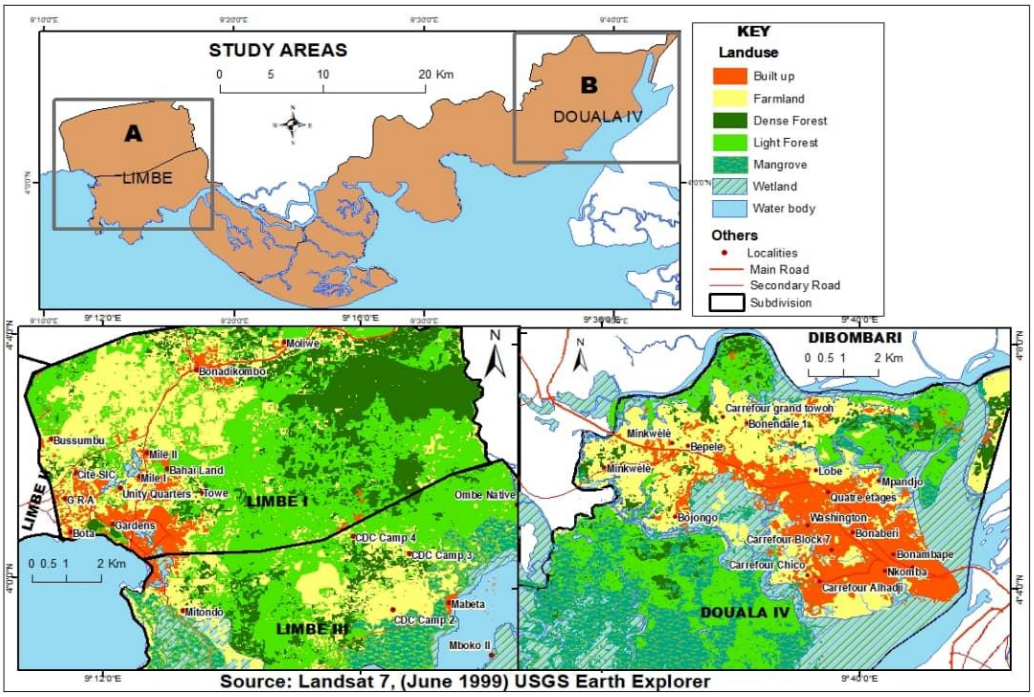


Map 3. LULC Situation for 1999 in the L1&3Ms and D4M

Source: Landsat 7 ETM+ 1999 and Fieldwork, 2023

4.1.3 Spatial Evolution of L1&3Ms and D4M in 2013

Map 4 presents the different LULC classes in 2013 in L1&3Ms and D4M and Figure 3 shows the surface area of the different LULC classes in 2013 in Kilometer square (km^2) in the study areas.

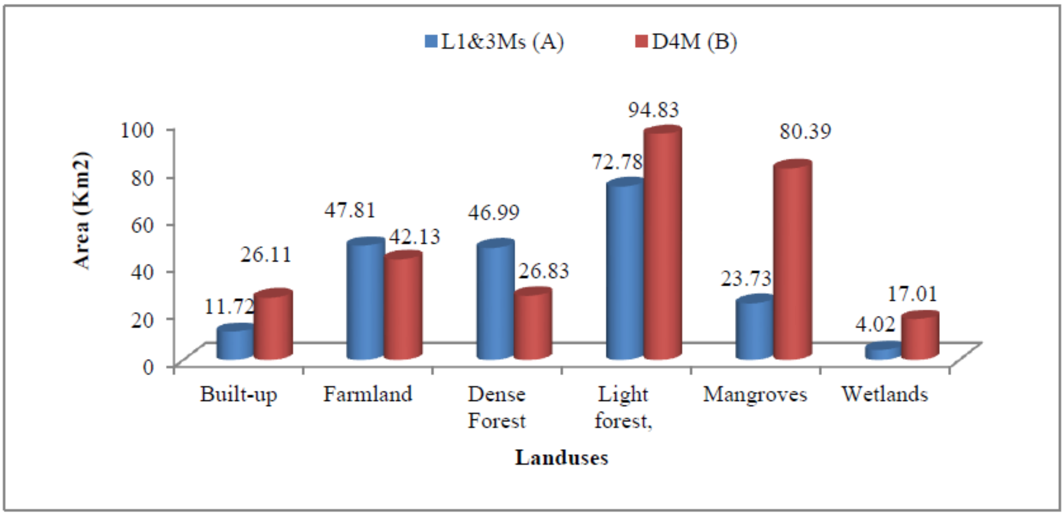
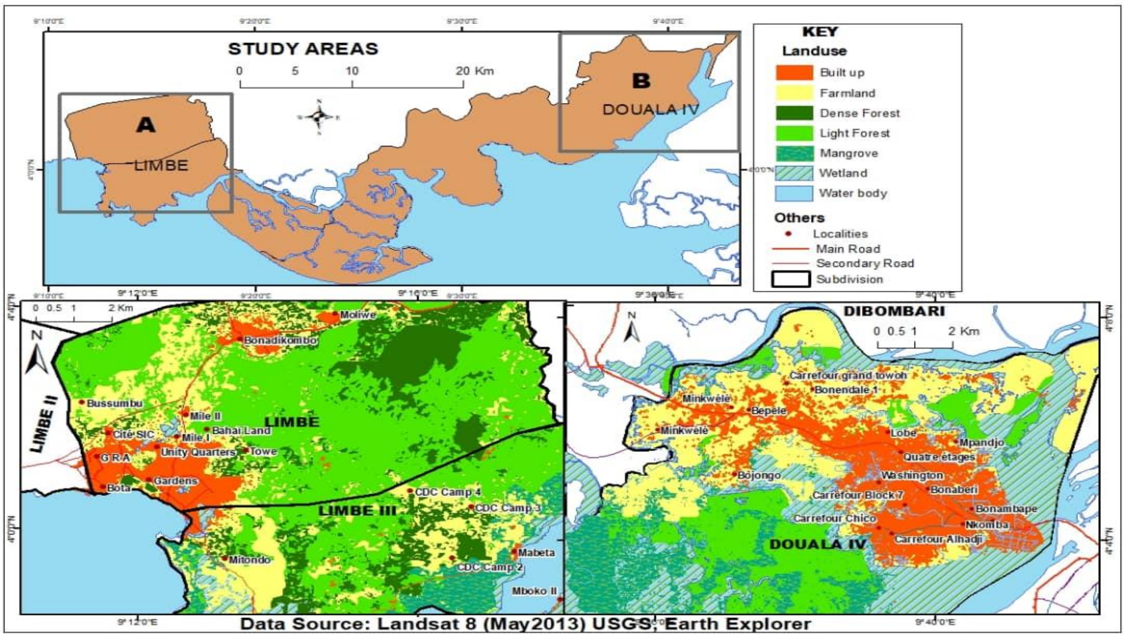


Figure 3. LULC Situations in 2013 in L1&3Ms and D4M

Source: Derived from Landsat 8 2013 LULC Data for D4M and L1&3Ms

From the cylinder (Figure 3), in 2013, built up occupied 11.72km^2 (7.41%) and 26.11km^2 (7.41%) of the total 207.79km^2 and 352.20km^2 of land cover of L1&3Ms and D4M while wetland vegetation occupied 4.02km^2 (1.93%) and 17.01km^2 (4.83%) in both study areas respectively. Findings from Figures 2 and 3, revealed that built up has increased by 6.29km^2 (3.03%) and 8.26km^2 (2.34%) between 1999 and 2013 in L1&3Ms and D4M respectively. In the same light, wetland areas reduced by -279km^2 (-1.35%) and –3.8km^2 (-1.08%) respectively. Thus, increases in built-up and farmland have contributed greatly to reducing the wetland areas of 2013 in L1&3Ms and D4M.



Map 4. LULC Situation for 2013 in the L1&3Ms and D4M

Source: Landsat 8, 2013 and Fieldwork, 2023

Findings from Figure 3 and Map 4, revealed that built up has increased by 6.29km^2 (3.03%) and 8.26km^2 (2.34%) between 1999 and 2013 in L1&3Ms and D4M respectively. In the same light, wetlands area reduced by -279km^2 (-1.35%) and –3.8km^2 (-1.08%) respectively. Thus, increases in build-up and farmland have contributed greatly to reducing the wetlands area of 2013 in L1&3Ms and D4M.

4.1.4 Spatial Evolution of L1&3Ms and D4M in 2022

Map 5 shows the different LULC patterns in 2022 in D4M and L1&3Ms while Figure 4 shows the surface area of the different LULC pattern in 2022 in Kilometer square (km^2) and in percentages (%) in the study areas. Prior to 2022, the study areas have witnessed dramatic changes in urban developments such as infrastructural developments (housing and roads, industrial/urban agricultural development) and population growth. All these developments and the services provided acted as a pulling factor to more urban development's resulting in dramatic decline in wetland areas.

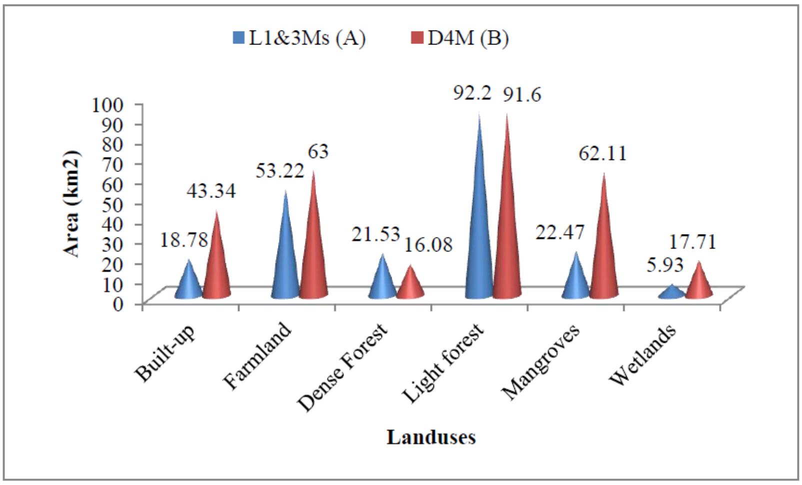
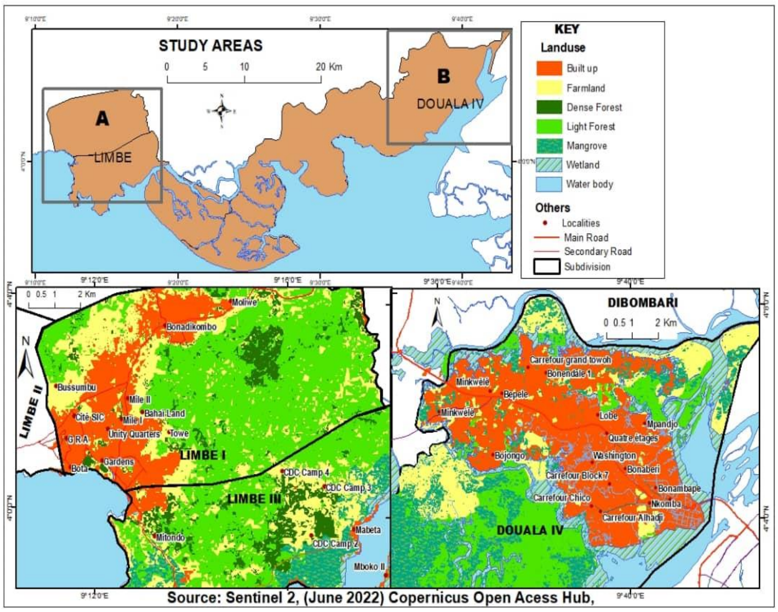


Figure 4. LULC Situations in 2022 in L1&3Ms and D4M

Source: Derived from Sentinel 2, 2022 LULC Data for D4M and L1&3Ms

From the cone (Figure.4) in 2022, built up area occupied 18.78km^2 (9.04%) and 43.34km^2 (12.31%) of the total 207.79km^2 and 352.20km^2 of land cover of L1&3Ms and D4M. Wetland vegetation occupied 2.93km^2 (1.41%) and 12.17km^2 (3.46%) in both study areas respectively. From Figures 3.3 and 3.4, built up has increased by 7.06km^2 (3.4%) and 17.23km^2 (4.9%) between 2013 and 2022 in L1&3Ms and D4M respectively. In the same light, wetland areas reduced by -1.09km^2 (-0.52%) and –4.84km^2 (-1.37%) respectively. Thus, an increase in farmland from 48.81km^2 -53.22km^2 (23.49% -25.61%) and 42.13km^2 - 63.00km^2 (11.96% - 17.89%), have contributed greatly to reducing the wetland areas of 2022 in L1&3Ms and D4M.



Map 5. LULC Situation of 2022 in D4M and L1&3Ms

Source: Sentinel 2, 2022 and Fieldwork, 2023

4.1.5 Change Detection of LULC changes from 1986- 2022

Within the past 36 years (1986-2022), dramatic changes have occurred in LULC in the study areas. This study also examined the magnitude / rate of change and trends of these LULC changes.

Magnitude of Changes in LULC

Over 36 years period (1986-2022), the largest part of the Bonaberi and Limbe I and III was covered by light forest and mangroves vegetation. Analysis of land cover changes as a percentage of the total area showed that wetland vegetation declined at the rate of 97.04km^2 and 191.54km^2 per year while land under agriculture increased by 335.44km^2 and 683.38km^2 per year and settlements/infrastructures by 294.33km^2 and 644.46km^2 per year in L1&3Ms and D4M respectively. These results show that land cover in the study area is highly dynamic. Noticeably, built-up density increased along the urban fringes than at the peripheries of the wetland while wetland vegetation decreased significantly through the entire period especially at the urban fringes. By 2013, most of the wetland vegetation had been converted to housing, industrial development, road infrastructure; urban agriculture, grassland and water, and a new road access to the wetland had been created. Table 3 presents magnitude of change per land cover class for each year in the study area.

Table 3. Magnitude of Change per Land Cover class for each year

		1999-2013		**1999-2013**		**2013-2022**	
LULC Classes		**L1&3Ms**	**D4M**	**L1&3Ms**	**D4M**	**L1&3Ms**	**D4M**
Built-up	Area	1.47	6.96	6.29	8.26	7.06	17.23
	%	0.7	1.98	3.03	2.34	3.4	4.9
Farm land	Area	2.39	57.42	10.09	6.12	4.41	20.87
	%	1.15	2.09	4.86	1.74	2.12	5.93
Dense forest	Area	-10.1	-6.94	-2.29	-22 .45	-5.12	-5.75
	%	-4.79	-1.97	-1.14	-1.05	-2.46	-1.62
Wetlands	Area	0.1	-1	-2.79	-3.8	-1.09	-4.84
	%	-0.05	0.28	-1.35	-1.08	-0.52	-1.37
Light forest	Area	11.16	78.1	32.63	7.32	19.42	-3.23
	%	5.37	-0.66	5.09	1.93	9.35	-0.92
Mangroves	Area	-9.89	-3.8	-11.18	-13.96	-1.26	-18.28
	%	-4.76	-0.87	-5.38	-1.62	-0.61	-7.75

Source: Extracted from Landsat 5 1986, Landsat 7 1999, Landsat 8 2013 and Sentinel 2, 2022

Table 3 presents the magnitude of change of LULC class for the study periods. From Table 3, it is evident that the magnitudes of change differ from one LULC class and period. While some land cover types (built-up and farmland) are witnessing an increase in land cover, others (wetlands, dense forest and light forest, mangroves) are witnessing a decrease. However, water bodies remain unchanged throughout the study period from the respective LULC maps. The most striking magnitude of periodic LULC dynamics was recorded by dense forest with a decrease of -4.79% in L1&3Ms as opposed to built-up for D4M that increased by 1.98% between 1986-1999. Between 1999 - 2013 wetlands reduced by the magnitude of -1.35 and -1.08 while built-up increased by 3.03% and 2.34% for all the Municipalities respectively. This implies that built up and farmland increased by 3.86km^2 (1.85%) and 64.38km^2 (4.07%) between 1986/1999 and 11.47km^2 (5.52%) and 38.1km^2 (10.83%) between 2013/2022 in L1&3Ms and D4M. These magnitudes of increases in built ups and farmlands thus posse significant implications on wetlands by causing losses in wetland areas in the studied areas.

Trends in LULC Change from 1986-2022

Base on the trends of LULC changes within the study areas, over the period of 36 years, some land uses have witnessed an increasing trends such as built-up and farmlands while other like dense forest, light forest and mangrove and wetlands have continuously witnessed a decrease in their respective area coverage. These increase and decrease in LULC area coverage are due to certain drivers such as population increase, increase infrastructural development and increase in housing developments in the study areas. Table 4 presents the trends in LULC from 1986-2022.

Table 4. Trends in LULC from 1986-2022 in L1&3Ms and D4M

LULC		1986-1999		1999-2013		2013-2022		1986-2022	
		L1&3Ms	D4M	L1&3Ms	D4M	L1&3Ms	D4M	L1&3Ms	D4M
Built-up	Area	0.08	0.35	0.32	0.41	0.35	0.85	0.75	1.63
	%	0.03	0.09	0.15	0.11	0.02	0.24	0.36	0.45
Farm land	Area	0.12	2.89	0.50	0.30	0.23	1.04	0.85	1.73
	%	0.05	0.11	0.24	0.08	0.11	0.29	0.41	0.49
Dense forest	Area	-0.50	-0.35	-0.11	-1.12	-0. 25	-0.28	-0.88	-0.82
	%	-0.24	-0.09	-0.05	-0.05	-0. 12	-0.08	-0.42	-0.23
Light Forest	Area	0.56	3.93	1.63	0.37	0.96	-0.16	2.07	0.059
	%	0.27	-0.03	0.25	0.096	0.46	-0.046	0.99	0.017
Mangroves	Area	-0.49	-0.19	-0.56	-0.698	-0.06	-0.91	-1.124	-1.81
	%	-0.23	-0.04	-0.27	-0.081	-0.030	-0.04	-0.54	-0.06
Wetlands	Area	0.05	-005	-0.14	-0.02	-0.05	-0.24	-0.2	-048
	%	-0.03	0.05	-0.06	-0.05	-0.03	-0.07	-0.96	-0.14

Source: Extracted from Landsat 5 1986, Landsat 7 1999, Landsat 8 2013 and Sentinel 2, 2022

Built-up continue to be on the increase while wetlands continue to experience a retreat. Within 13 years (1986-1999) built-up increased by 0.08km^2 (0.03%) and 0.35km^2 (0.09%) while within 14 years (1999-2013) it increased by 0.32km^2 (0.15%) and 0.41km^2 (0.11%). Also within a shorter period of 9 years (2013-2022) built-up 0.35km^2 (0.02%) and 0.85km^2 (0.24%) which is greater than what operated in the previous year indicating that as the years go by, the trends of built-ups also increases. Within 36 years (1986-20220 built-up increased by 0.75km^2 (0.36%) and 1.63km^2 (0.45%) from. This implies that the highest percentage of increase in built up was experienced in 2022.

On the other hand, wetland area retreated by 0.05km^2 (-0.03%) and -0.005km^2 (-0.014%) within 13 years, by -0.14km^2 (-0.06%) and -0.02km^2 (-0.05%) within 14 years, by -0.05km^2 (-0.03%) and -0.24km^2 (-0.7%) within 9 year and by -0.2km^2 (-.96%) and -0.48km^2 (-0.14%)

within 36 years. By implication, as Build-up continues to increase, wetlands will continue to retreat at a very rapid rate. Figure 5 shows the periodic rate of LULC from 1986-2022.

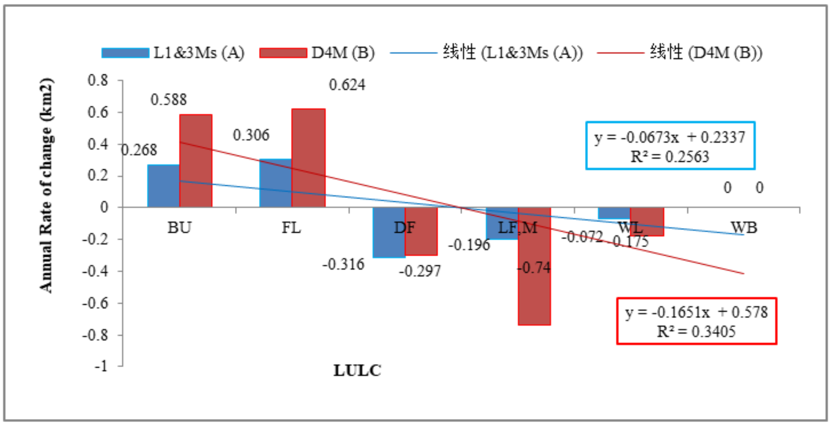


Figure 5. Periodic Rate of Change of LULC Types (1986-2022)

Source: Extracted from Landsat 5 1986, and Sentinel 2, 2022

Wetland vegetation was declining at the rate of -97.04km^2 and -191.54km^2 per year while settlements/infrastructures by 294.33km^2 and 644.46km^2 per year over the same 36 year period in L1&3Ms and D4M respectively. Comparatively, more wetlands are disappearing in D4M by -191.54km^2 (-54.23%) than L173Ms -97.04km^2 (-38%) owing to the increasing built-ups (644.46km^2) and farmlands (683.38km^2) compared to L1&3Ms (294.33km^2 and 335.44km^2).

Between 1984 and 2022, land use pattern of D4M/L1&3Ms had undergone significant mutations which are attributed in population and this resulted to increase in demand for land for settlement. The need for sustainable wetland management in the study area is therefore no longer a buzzword but an urgent appeal. The complex interrelationships of social, political, economic, demographic, technological, and cultural factors resulted to LULC change especially driven by urban developments. By the year 2005, the population of L1&3Ms stood at 101839 as opposed to 250626 for D4M (NIS, 2010). Households indicated that housing construction was the principal driver of LULC with mean scores of 2.88 and 3.03 on a scale of 4 for L1&3Ms and D4M respectively.

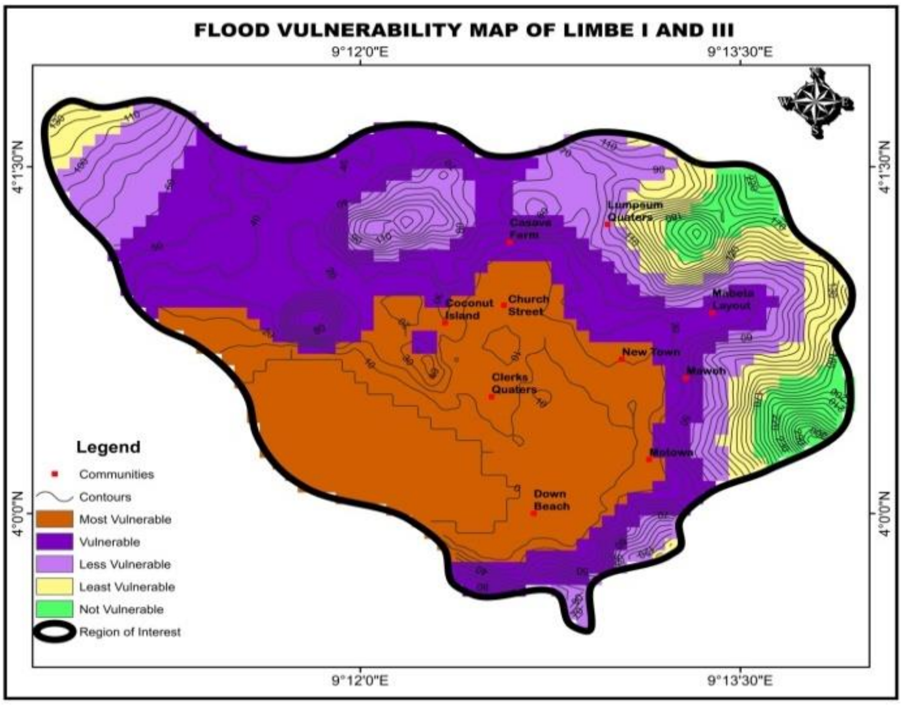
5. Implications of LULC Change on Wetland Regulating Services

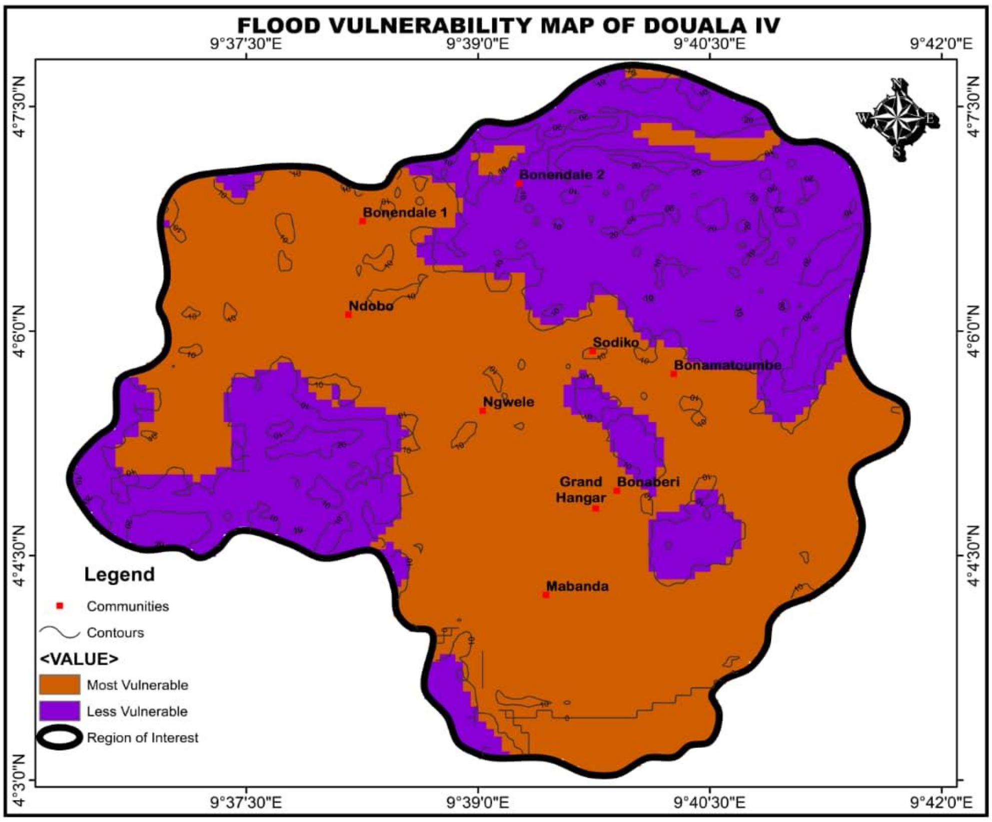
The implications of wetland transformation included reduction in wetland regulating ecosystem services such as exposures of coastal communities to flooding (Map 7) and water contamination. Plate 1 illustrates the use of mangrove as a source of fuel by the population in the Limbe. These indigenous actions which are a means of livelihoods have over time contributed to reducing the wetland areas, loss of mangroves and wetland ecosystem services.

Plate 1. Harvesting of mangrove for fuel wood in Limbe

Harvested mangroves (A), Fresh fish intended to be smoked (B) and Mangrove used to smoke fish (C)

Five categories of neighbourhoods are found in L1&3Ms and two for D4M base on predictive Map of flood vulnerability. These categories include; vulnerable, less vulnerable, least vulnerable and most vulnerable neighbourhoods. The most vulnerable communities include Down Beach, Clerks Quarter, Church Street, Motowo, Coconut Island and New Town for L1&3Ms and Mabanda, Grand Hanger, Ngwele, Bonendale I, Sodiko and Ndobo for D4M. These are areas whose wetlands have completely disappeared due to urbanization resulting to a loss of the provisioning services of wetlands. The less vulnerable area is Lumpsum while the vulnerable areas are Cassava Farms, Mabeta New Layout and Mawoh (L1&3Ms) and Bonasama, Bonamatoube, Bilingue, Rai and Bonendale II (D4M). Map 7 shows vulnerable floods neighbourhoods in the study areas.





Map 7. Predictive Map of Flood Vulnerability for L1&3Ms and D4M

Source: Fieldwork, 2023

Thus, most vulnerable areas are almost permanent flooding all through the rainy season and especially the peak months of August and September with very high probability levels. These are functional flood plains where water has to flow or be stored in times of flood. With regards to flooding, the nature of disastrous floods has also increased in recent years, with flash floods and coastal flooding increasingly frequent. Flooding in D4M is mostly accounted for by engineering factors such as poor drainage facilities, haphazard construction of settlements and blockage of drains by refuse amongst others.

Flooding in Limbe has been attributed mostly to Sea Level Rise (SLR) and destruction of mangroves for settlement. On that account, populations in these areas, especially low elevation coastal zones are most vulnerable to flooding arising chiefly from SLR, poor urban governance, poor drainage facilities, inadequate and poorly designed drains and haphazard construction of settlements. The low elevation zones considered to be less than 10m in altitude. These zones are heavily populated and despite the vulnerability of these localities to floods, the population keeps growing rapidly. Plate 1 below indicate flooding in Douala IV and Limbe Municipalities after a heavy downpour on the 9th and 15th of October 2022.

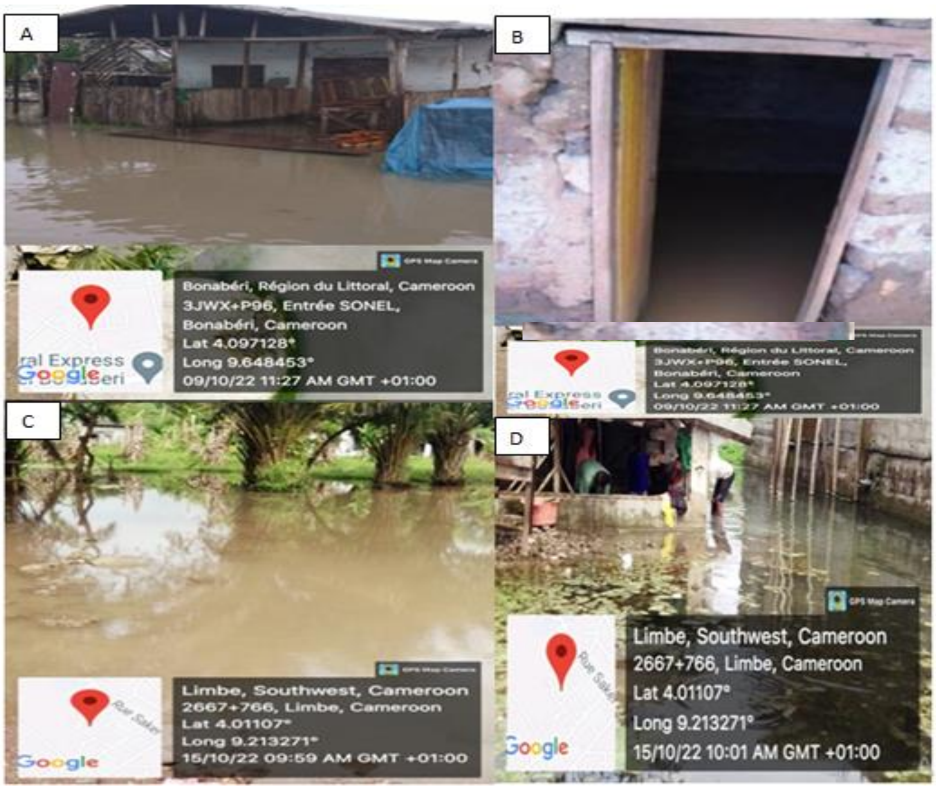


Plate 1. Flooding in Mabanda (A), Bonendale (B), Down Beach (C), Clerk's Quarters (D) and Height of Retreated Floods (E) (Rai-D4M)

Meteorological risks (flooding) constituted a significant threat in the coastal areas of L1&3Ms and D4M, and urban development into the wetlands are considerably reducing the regulating functions of wetlands. Pearson product moment correlation between LULC dynamic and flooding in the Municipalities is presented on Table 5.

Table 5. Pearson Product Moment Correlation Coefficient between LULU change and flooding

			Pearson's correlation	95% confidence level (0.05), 2-tail	df	Decisions
L1&3Ms	LULC & flooding	1986-2022	0.99	.811	4	Statistically very strong
D4M	LULC & flooding	1986-2022	0.82	.811	4	Statistically strong

Changes in LULC over the study areas had a significant positive relationship with flooding. This implies that an increase in LULC dynamics leads possible increase in flooding in the study areas. Kappa Accuracy Assessment classifications yielded overall accuracies above 80%, with Kappa statistics of 80.35, 82.14, 87.5 and 92.85 for 1986, 1999, 2013 and 2022 study periods respectively for L1&3Ms and D4M.

6. Discussion

The results from the spatio-temporal LULC analysis indicate a negative change in wetlands, mangroves, farmland and dense forest while farmland and build-up indicted an increase. These changes were attributed to population increase, infrastructural development, the presence of higher academic and professional institutions, socio-economic activities and the improvement in technology in both study areas. This corroborates the findings of Balgah 2005, 2007; Githui, Mutua & Bauwens 2009; Idoko and Bisong 2010; Lambi 2001; Lambin and Geist 2007; Balgah 2010, Balgah and Nformi 2017; Fombe and Acha (2018), they revealed that most significant changes in land use-land cover are related to agricultural expansion, settlement and urban infrastructural development. They attribute these changes to population increase, economic factors, technological factors and urbanization. The destruction of the light forest, mangroves and wetlands land cover into farmland and build-up land use has resulted in the reduction and modification of wetland ecosystem services. The growing population of L1&3Ms and D4M has led to the conversion of wetlands thereby exposing the coastal areas to flooding especially in Mabanda, Ndogbo, Rain Ngwele, Clerk's Quarters, Down Beach, Mbonjo, New Town, Cassava Farms and the Mawoh areas. The exposure of the population to flooding is also attributed to colonization of river banks and channels which obstruct the natural flow of water in these areas. The increasing colonization of wetlands has also increase the problem of water contamination which is accelerating due to poor governance.

7. Conclusion and Recommendations

This study evaluated the impacts of LULC changes on the coastal wetland regulating ecosystem services in D4M and L1&3Ms over 36 years (1986–2022). The findings displayed severe decline ($-82.53km^2$ and$-1.63km^2$) of wetlands, light forest, mangroves and dense forest, largely because of increase built-up area and cultivated land (3.36 km^2 and 1.6 km^2) for both study areas respectively. The changes in the LULC during the study periods driven primarily by urban growth adversely affected the provisioning ecosystem services provided by wetlands and other landcovers. This suggest the need for intervention to maintain wetlands for storm water management, water supply, water treatment, recreation roles and other wetland ecosystem services (McInnes, 2013).

One of the principal factors contributing to increasing colonization of wetlands in the study areas has been poor implementation of environmental policies. Despite the adoption of numerous strategies and plans for sustainable management of wetlands, the current problem of its implementation still remains. Field studies indicate that land use plans are poorly put in use in the study areas. The poor implementation of this significant document makes it problematic for satisfactory urban planning to be accomplished in D4M and L1&3Ms. The result, therefore, is the haphazard allocation of land uses without taking into account their compatibility with the environment and other land uses, and the safety of the population. For instance, the residential land uses of Bonnassama, Mabanda, Ndobo, Down Beach, Clerk's Quarter and New Town exposes the settlers to sea intrusion and flood hazards. Study recommends proper planning and implementation of land use plans while considering importance of ecosystem in the study Municipalities.

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Authors contributions

Amenkeng Lucienne went to the field, collected and analysed the data. She drafted the research design and protocol which were corrected by Dr. Tata Sunjo and Prof. Balgah Sounders. She equally drafted the manuscript which was revised by Dr. Tata Sunjo and Prof. Balgah Sounders.

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The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Data sharing statement

No additional data are available.

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